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The influence of the selected technological factors on the quality of bimetallic castings a*lloy steel-silumin*

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Abstract

The work presents the research results of the influence of the selected technological factors on the improvement of bimetallic castings *alloy steel-silumin*. The following alloy steel grades were used for the research: X6CrNiTi18-10, X39Cr13 and HS6-5-2. The sets of the mentioned steel grades were alphinated in silumin AlSi5 and were poured with this silumin or complex silumin AlSi5Ni5Cu4MgCrMoWV into the casting mold obtaining bimetallic castings as a result. Moreover, the following technological factors of the process of bimetallic casting production were analyzed: the time from removing of the set from the alphinizing bath till pouring it with the silumin into the casting mold "τ_p", the temperature of the initial heating of the casting mold "$t_{2,0}$" and the temperature of the silumin for pouring of the casting mold "t_z". It follows from the presented results that the best connecting quality of the analyzed castings is obtained when using: the possible short time "τ_p" and low temperature values "$t_{2,0}$" and "t_z".

Keywords: Innovative casting technologies, Bimetallic casting, Alphinizing, Alloy steels, Silumins

1. Introduction

Connecting silumins with ferroalloys in bimetallic casting is performed with the help of alphinizing. This process is based on dipping application of the silumin coating on the unit made from the ferroalloy (the so called "set"). According to the data presented in works [1, 2] the coating on the alloy steels consists of three layers.

The first one, from the side of the steel ground, is constructed from the basic phase AlFe containing composite additives of the alloy steel, the second one is the phase AlFe containing the main alloy additive of the given steel. Together these layers form the so called diffuse transition layer of the alphinating coating. It connects the steel unit with the third coating layer made mainly of the silumin phase used in the alphinizing process. This layer also contains lamellar and wall precipitates of the intermetallic phases which recrystallize from the liquid appeared as a result of mixing the silumin in the alphinizing bath with the melting phases of the transition layer. Moreover, if the alphinized steel contains carbides they can appear in all layers of the coating formed on it. In order to obtain bimetallic casting it is necessary to place the set with the coating into the casting mold and pour it with silumin. As a result of smelting of the external (silumin) layer of the coating with the silumin poured into the casting mold the bimetallic casting of the system *alloy steel – silumin* is obtained with a diffuse transition layer connecting both alloys.

It follows from the data presented in works [3, 4] that there is the same structure of the corresponding elements of the alphinizing coating and the connection in the bimetallic casting. The thickness of the transition layer is different, as well as the area of appearance of the free phases and probably of the carbides. The transition layer in the connection has a smaller thickness in comparison to the coating. Free precipitations of the intermetallic phases and the carbides in the connection can appear in the distance from the steel ground which is bigger than the total thickness of the coating. A generalized scheme of the connection of bimetallic casting made in the system *alloy steel – silumin* is shown in Figure 1.

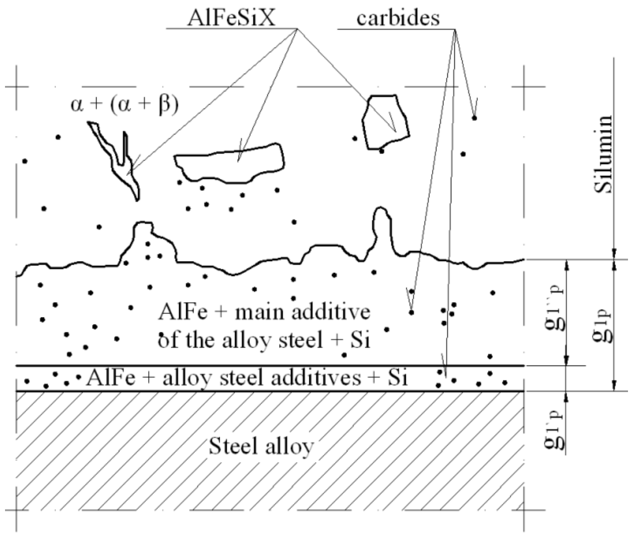


Fig. 1. Generalized scheme of the connection of bimetallic casting made in the system *alloy steel – silumin*

In the presented scheme the total thickness of the transition layer of the connection is marked as "g_{1p}" and the thickness of the compound layers as "$g_{1'p}$" – the layer situated immediately on the alloy steel and "$g_{1''p}$" – the layer adjacent to the silumin of the bimetallic casting. Intermetallic phases are marked with the symbol AlFeSiX, apart from Al, Fe and Si they can contain any atom configuration determining the alloy additives of the composing materials of the given bimetallic casting.

It follows from the analysis of the connection structure via alphinated layer of the bimetallic casting that to obtain it correctly and with high quality it is necessary to meet the following conditions:

- smelting of silumin poured into the casting mold (which is the base of the bimetallic casting when hardened) with the external layer of the alphinizing coating,
- preserving the continuity of the layer of the intermetallic phases immediately neighbouring the set after it is poured with silumin,
- obtaining the highest possible homogeneity of the silumin structure in the environment of the alphinated layer [3].

The final condition to obtain the above characterized connection of high quality is to make the correct alphinizing coating on the set. It is achieved by correct preparation of the set and using optimal parameters of the coating making process. More than that, to obtain the correct connection, it is necessary to optimize the operating and processing parameters connected with bimetallic casting making. Regarding the correctness of the connection, the following factors in the process of bimetallic casting making are the most important:

- the time from taking the set out of the alphinizing bath till pouring it with silumin into the casting mold "τ_p",
- the temperature of the initial heating of the casting mold "$t_{2,0}$",
- the temperature of the silumin for casting mold pouring "t_z" [3].

It is necessary to assume that in order to obtain the correct connection of the coating with the silumin poured into the casting mold the shortest time "τ_p" will be required. The coating after being taken out of the bath crystallizes very fast, and the oxide Al_2O_3 forms on its surface. Due to high affinity of aluminum and oxygen and high temperature of the coating after removing it from the bath the thickness of the oxide layer increases intensively with the time. Thus, the set with the coating should be placed into the casting mold and poured with silumin so fast that the thickness of the Al_2O_3 layer could be disrupted by the forces following from the influence of the liquid silumin during pouring of the metal mold.

The temperature of the initial heating of the casting mold "$t_{2,0}$" influences the rate of crystalline growth in the cast and the possibility of appearance of gas porosity in the area of connection.

The temperature of the silumin for pouring "t_z" should ensure smelting of the coating by the silumin poured into the casting mold but it cannot cause complete melting of the diffuse transition layer.

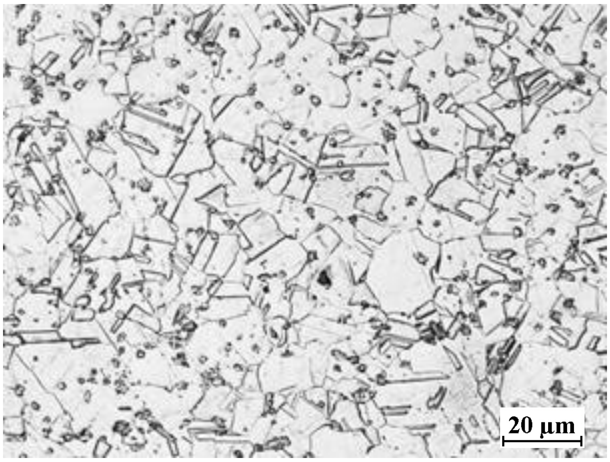
2. The methodology of the research

The following alloy steel grades were used in the research: acid-resisting steel X6CrNiTi18-10 (1H18N9T), stainless steel X39Cr13 (4H143) and high-speed steel HS6-5-2 (SW7M). The chemical composition and microstructure of the mentioned steels is presented in Table 1 and Figure 2 (a-c) correspondingly.

Table 1.
Chemical composition of the alloy steel grades under analysis

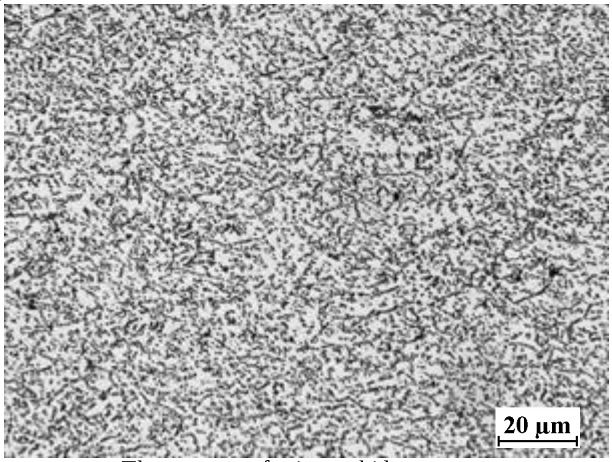
Steel grade	Average content, %									
	C	Si	Ni	Cr	Mn	Ti	Fe	W	Mo	V
X6CrNiTi18-10	0.06	0,41	9,31	17,33	1,74	0,264	70,1	<0,01	0,2	0,07
X39Cr13	0.41	0,43	0,42	13,90	0,54	0,104	83,9	<0,01	0,01	0,03
HS6-5-2	0.91	0,27	0,15	4,11	0,36	0,008	79,7	6,75	5,40	1,76

a)



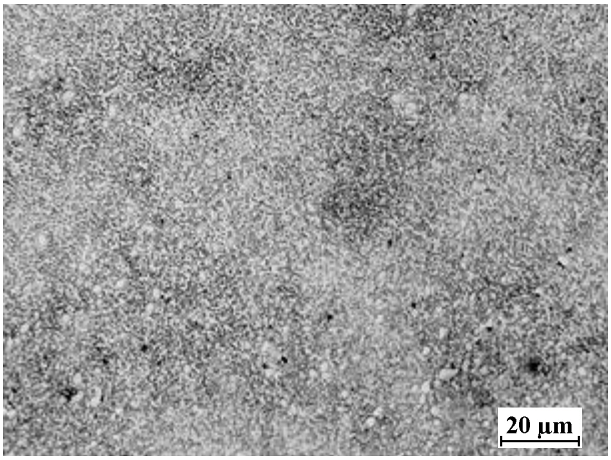
The structure: austenite, carbides

b)



The structure: ferrite, carbides

c)



The structure: ferrite, carbides

Fig. 2 (a-c). Microstructure of the alloy steel grades under analysis: a – X6CrNiTi18-10, b – X39Cr13 and c – HS6-5-2

The cylinders (the sets) with the diameter of d = 10 mm and the length of l = 70 mm were made from the analyzed alloy steel grades, and then the coating was made on them by dipping them in the silumin AlSi5. The silumin bath had the temperature t = 750±5°C, and the dipping time was τ = 180s. Before placing to the bath, the steel cylinders had been cleaned mechanically, chemically degreased and preheated to the temperature of 50°C.

In order to obtain bimetallic castings, the steel units with the coating were placed into the metal mold made from pearlitic gray iron and then were poured with synthetic silumin AlSi5 or with complex silumin AlSi5Ni5Cu4Mg CrMoWV. The chemical composition of the used silumins is given in Table 2.

The following temperature values were used for the silumin for pouring the bath: t_z = 750, 800 and 850°C. The time from removing of the set from the alphinizing bath till pouring it with the silumin into the casting mold was 15, 30, 45 and 60 seconds. The temperature of the initial heating of the metal mold was within the range of $t_{2,0}$ = 100÷250°C with 50°C increments.

Metallographic tests were made with the use of a Nikon MA200 Eclipse optical microscope equipped with a digital camera and with the use of a HITACHI S-3000N electronic scaling microscope.

Table 2.
Chemical composition of the silumins under analysis

Silumin grade	Average content, %									
	Si	Ni	Cu	Cr	Mn	Ti	Fe	W	Mo	V
AlSi5	4.69	0.04	0.09	0.06	0.13	0.02	0.46	-	-	<0.01
AlSi5Ni5Cu4-MgCrMoWV	4.56	4.66	3.54	0.17	0.09	0.02	0.48	0.26	0.33	0.17

3. Research results

Figures 3-5 (a-d) present the microstructure of the bimetallic castings in the area of connecting of the silumin AlSi5 with the analyzed alloy steel grades (X6CrNiTi18-10, X39Cr13 and HS6-5-2) made with applying of different times from taking the set out of the alphinizing bath till pouring it into the casting mold "τ_p".

It follows from the presented data that irrespective of the set material for the time τ_p = 15 and 30s due to a relatively small thickness of the oxide layer Al_2O_3 appeared on the surface of the alphinizing coating its smelting with the silumin of bimetallic casting took place (Fig. 3-5 (a-b)).

For the time τ_p = 45s in the area of connection of the coating with the silumin of bimetallic casting, discontinuity of the connection appears in some places. In the case of castings with sets from the steel X6CrNiTi18-10 (Fig. 3c) and X39Cr13 there are porosities which probably remained after tearing off large fragments of the oxide layer Al_2O_3.

In the case of casting *HS6-5-2–AlSi5* (Fig. 5c) the thickness of the oxide layer only caused its partial destruction by the silumin poured into the casting mold. A large fragment of the layer Al_2O_3 is clearly seen and due to it smelting of the coating with the silumin of the bimetallic casting was not possible. Irrespective of the set material (Fig. 3-5d) when the temperature was τ_p = 60s, the large thickness of the oxide layer caused its destruction by the shear forces followed from the influence of the silumin poured into the metal mold. Smelting of the alphinizing coating with the silumin of the bimetallic casting did not occur.

Taking it into account, it is necessary to accept that in order to obtain a homogeneous structure of the silumin in the area of connection of the bimetallic casting, the time from taking the set out of the alphinizing bath till pouring it with the silumin into the metal mold cannot be more than τ_p = 30s.

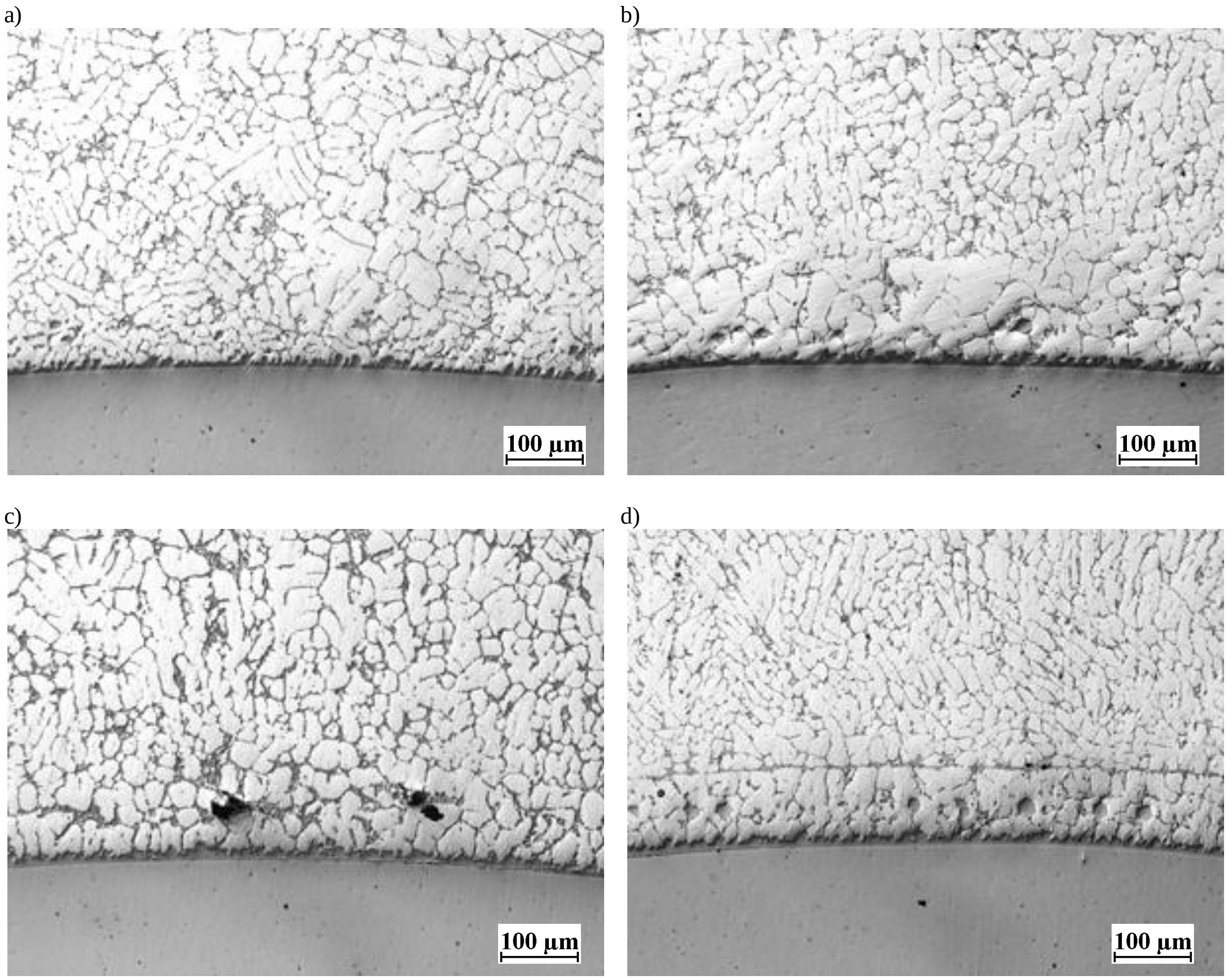


Fig. 3 (a-d). Microstructure of the connecting area of the bimetallic casting *X6CrNiTi18-10 – AlSi5* made with the different times from taking the set out of the alphinizing bath till pouring it into the metal mold "τ_p": a – 15s, b – 30s, c – 45s i d – 60s

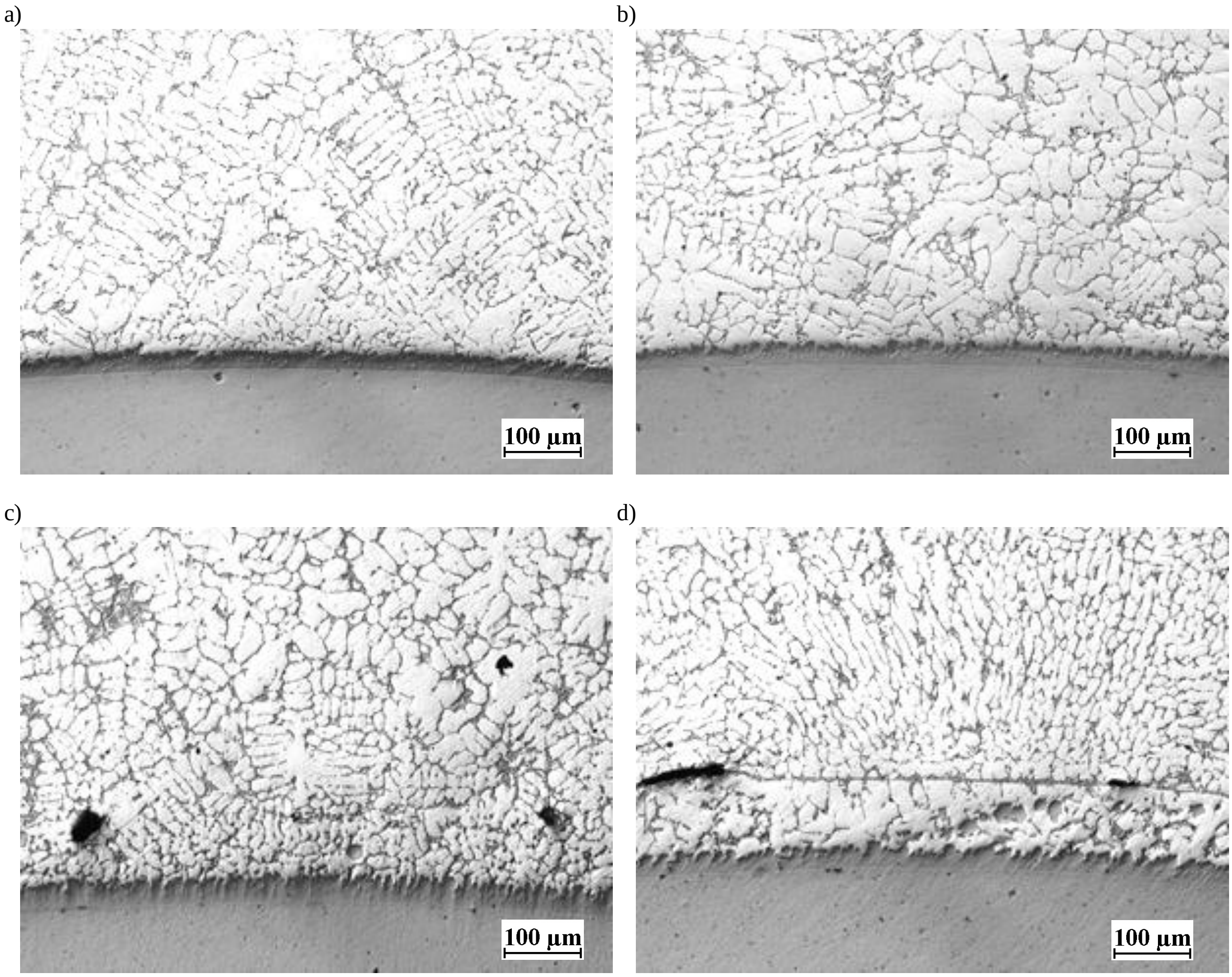
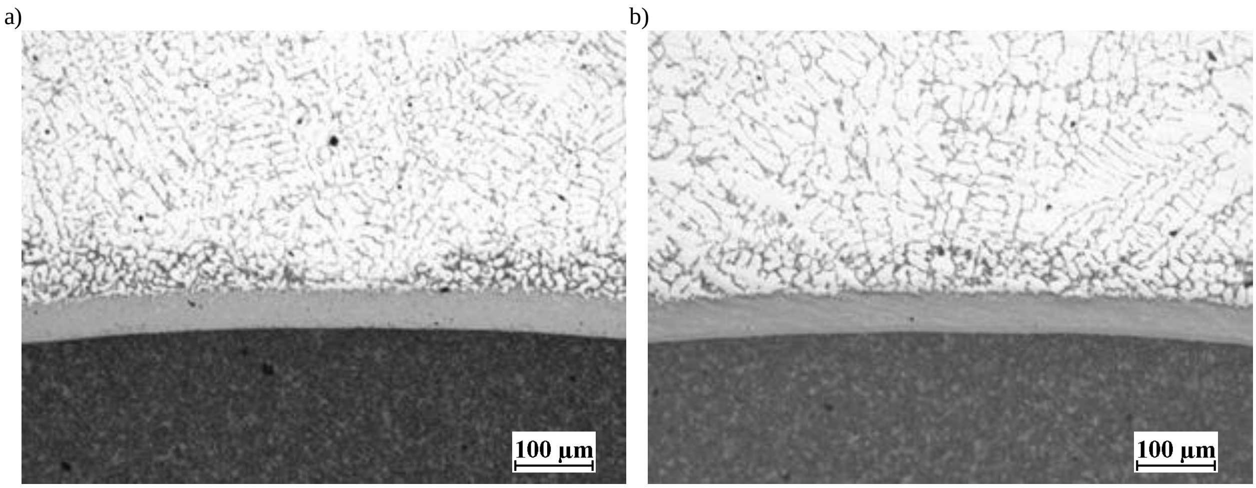


Fig. 4 (a-d). Microstructure of the connecting area of the bimetallic casting *X39Cr13 – AlSi5* made with the different times from taking the set out of the alphinizing bath till pouring it into the metal mold "τ_p": a – 15s, b – 30s, c – 45s i d – 60s



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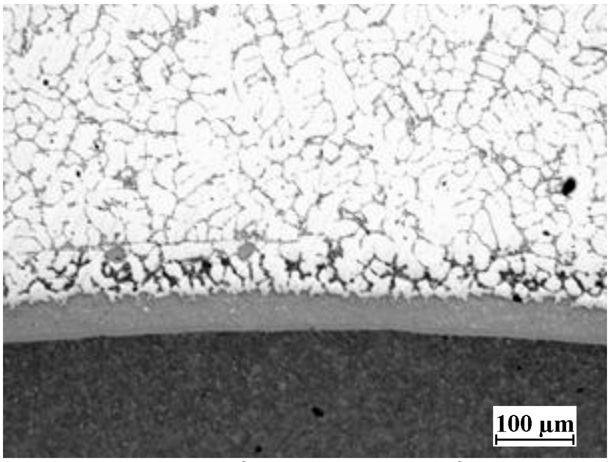


d)

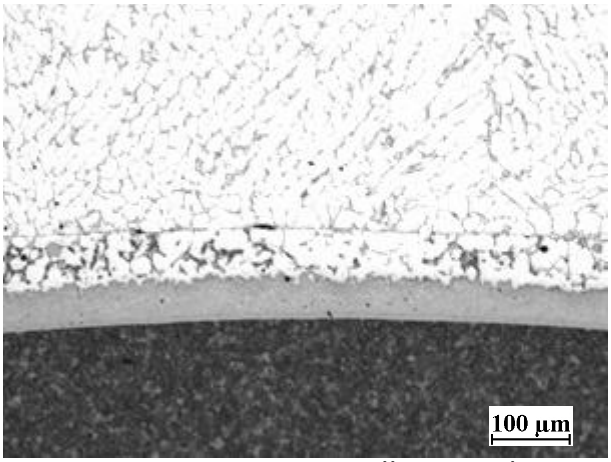
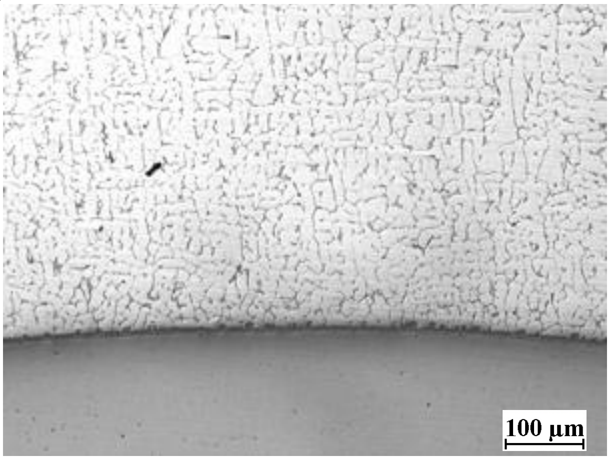


Fig. 5 (a-d). Microstructure of the connecting area of the bimetallic casting *HS6-5-2 – AlSi5* made with the different times from taking the set out of the alphinizing bath till pouring it into the metal mold "τ_p": a – 15s, b – 30s, c – 45s i d – 60s

Figures 6-8 (a-d) show the microstructure of the bimetallic casts in the area of connection of the silumin AlSi5 with the analyzed alloy steel grades obtained with different temperature values of the initial heating of the casting mold "$t_{2,0}$". As a result, for all analyzed kinds of the sets irrespective of temperature value "$t_{2,0}$" relatively small porosity appears in the silumin part. The differences in the microstructure of the presented bimetallic castings lay in the different size of the phase components of the silumin of the bimetallic casting.

For the smallest temperature value $t_{2,0}$ = 100°C the heat withdrawal rate from the silumin part of the bimetallic casting and its rate of crystalline growth were the highest which caused large silumin AlSi5 phase crushing. When the temperature "$t_{2,0}$" increased to the value of 150°C, 200°C and 250°C, the rate of crystalline growth of the silumin decreased and as a result a growth in mainly dendrites size of phase α was obtained. It follows from the presented data that irrespective of the set material the decrease in the temperature value of the initial heating of the casting mold "$t_{2,0}$" causes components crushing of the silumin microstructure of the bimetallic casting.

a)



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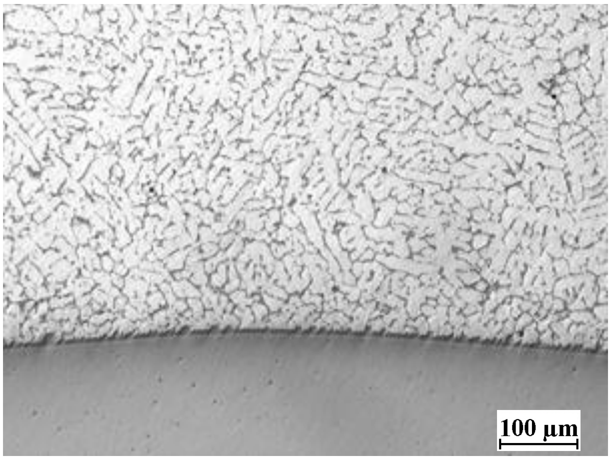


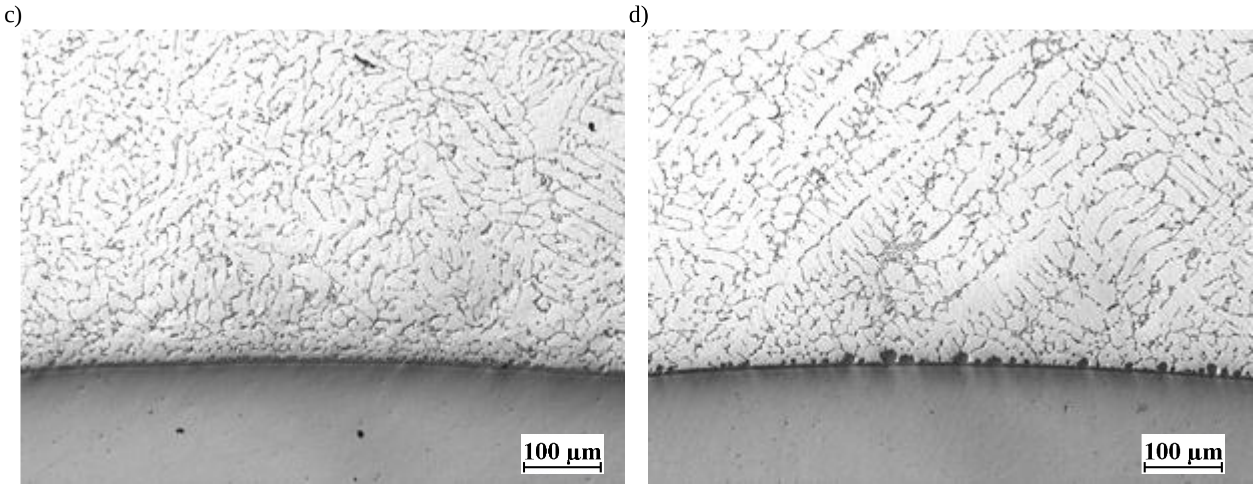


Fig. 6 (a-d). Microstructure of the connecting area of the bimetallic casting *X6CrNiTi18-10 – AlSi5* made with the application of different values of the initial heating of the metal mold "$t_{2,0}$": a – 100°C, b – 150°C, c – 200°C and d – 250°C

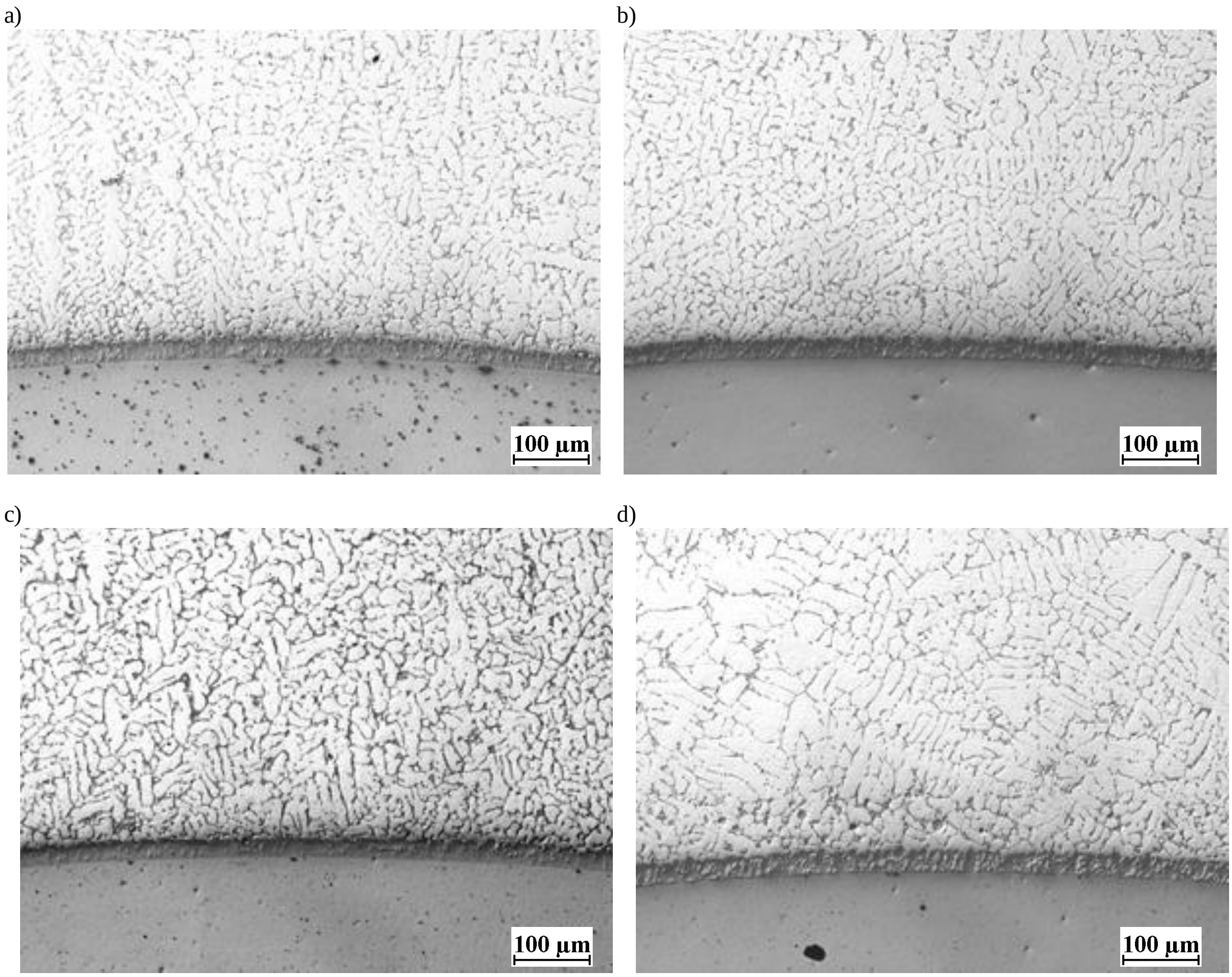


Fig. 7 (a-d). Microstructure of the connecting area of the bimetallic casting *X39Cr13 – AlSi5* made with the application of different values of the initial heating of the metal mold "$t_{2,0}$": a – 100°C, b – 150°C, c – 200°C and d – 250°C

a) b)

c) d)

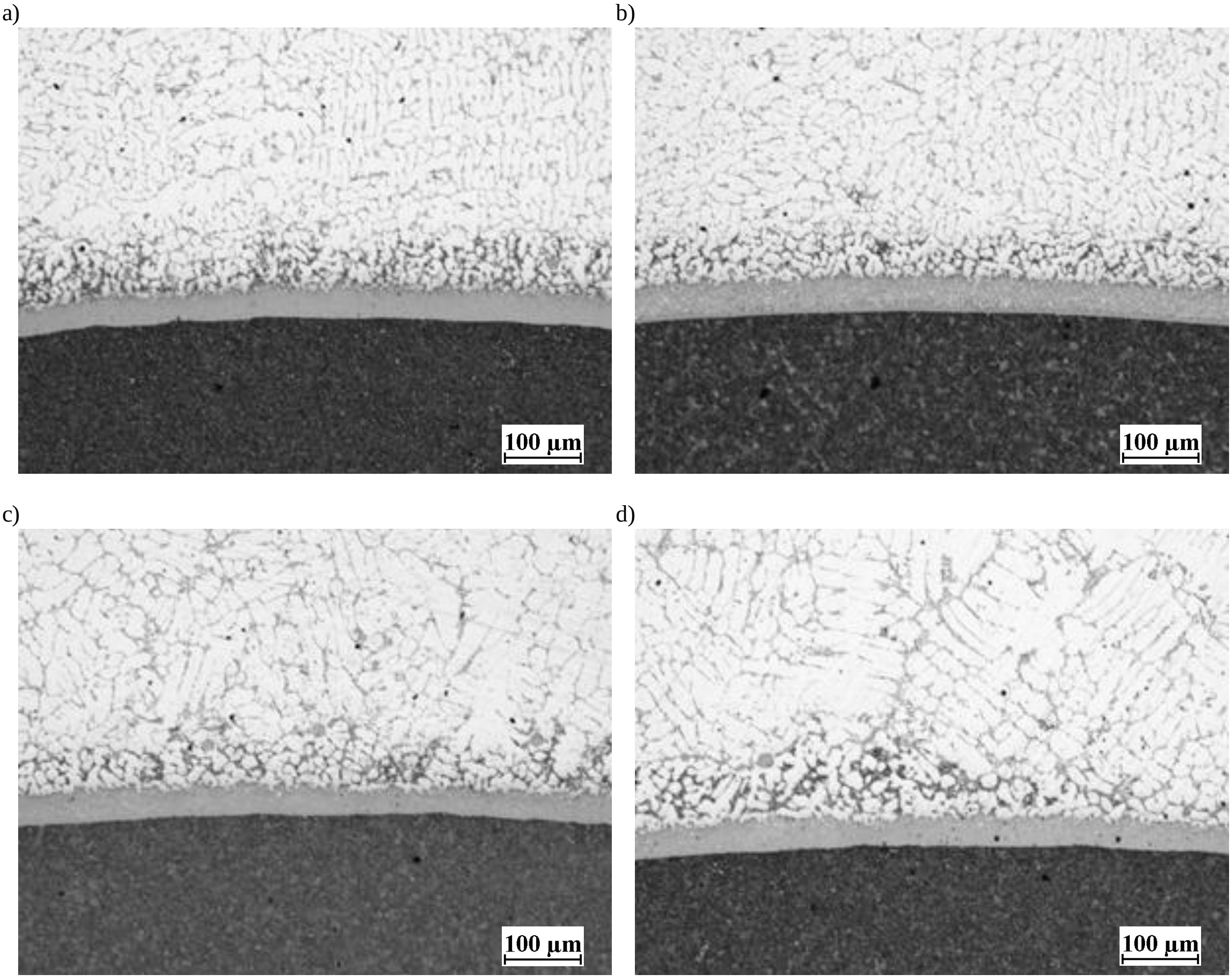


Fig. 8 (a-d). Microstructure of the connecting area of the bimetallic casting *HS6-5-2 – AlSi5* made with the application of different values of the initial heating of the metal mold "$t_{2,0}$": a – 100°C, b – 150°C, c – 200°C and d – 250°C

For testing the influence of the temperature of the silumin poured into the casting mold "t_z" on the quality of the obtained connection in the bimetallic casting, the sets made of the analyzed alloy steel grades after being alphinated in silumin AlSi5 were poured into the casting mold with the complex silumin AlSi5Ni5Cu4MgCrMoVW. For under- and almost eutectic silumins depending on the thickness of the mold casting wall, concentration of silicium and alloy additives, the temperature of pouring is within the range of $t_z = 680 \div 750$°C [5].

In the case of bimetallic castings with application of the alphinizing process, taking into account the necessity of external (silumin) coating layer smelting and destruction of the Al_2O_3 oxide layer a higher value of the temperature "t_z" should be considered. The following temperature values t_z = 750, 800 and 850°C were analyzed. Too high temperature of the silumin poured into the casting mold may cause excessive smelting of the alphinizing coating (penetrating into the transition layer) or its complete melting in certain areas causing, as a result, local losing of continuity of the layer "g_{1p}" in the casting. Figures 9-11 (a-c) show microstructure of the bimetallic castings in the area of connection of the silumin AlSi5Ni5Cu4MgCrMoVW with the analyzed alloy steel grades obtained at different temperature values of "t_z".

a)   b)

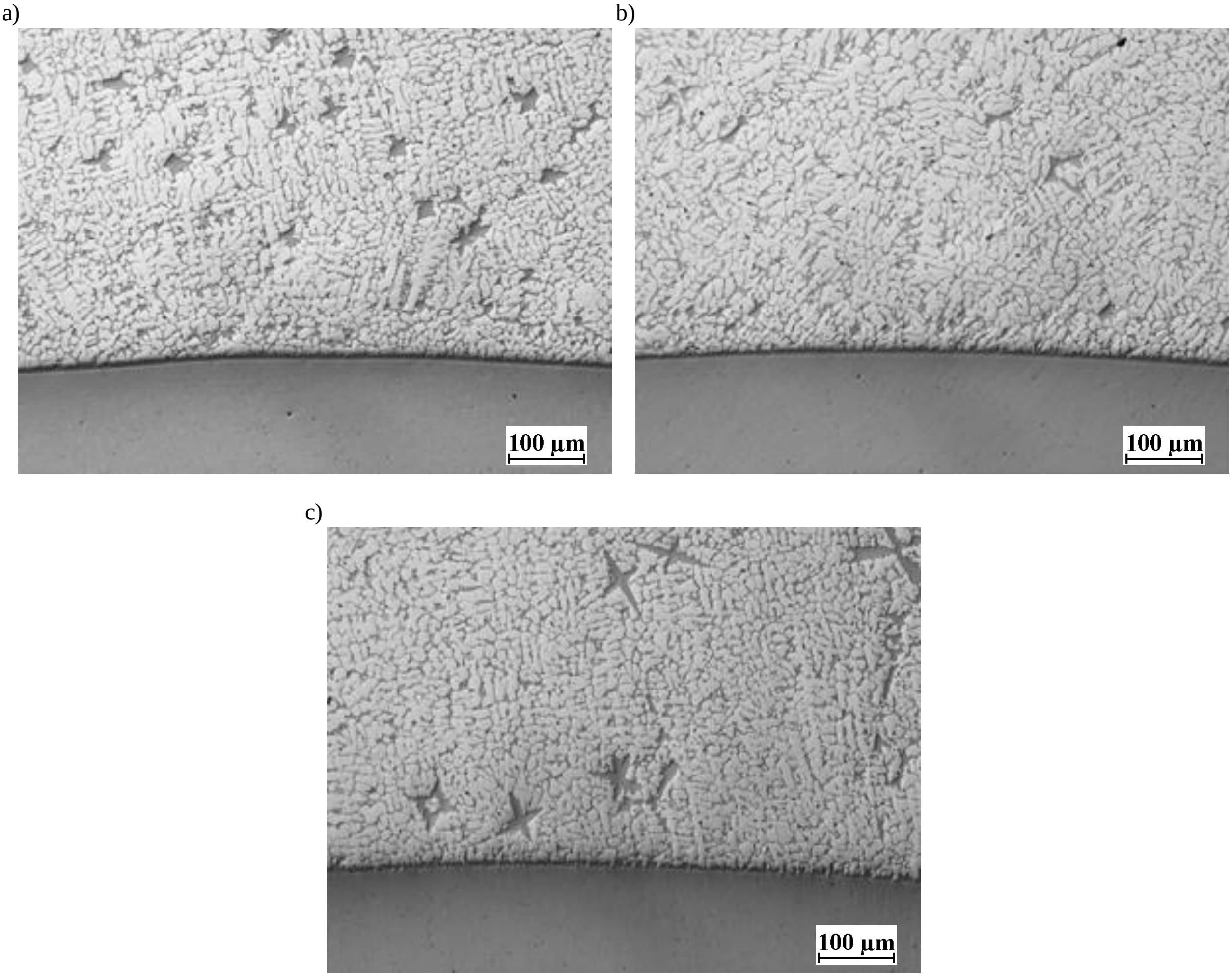
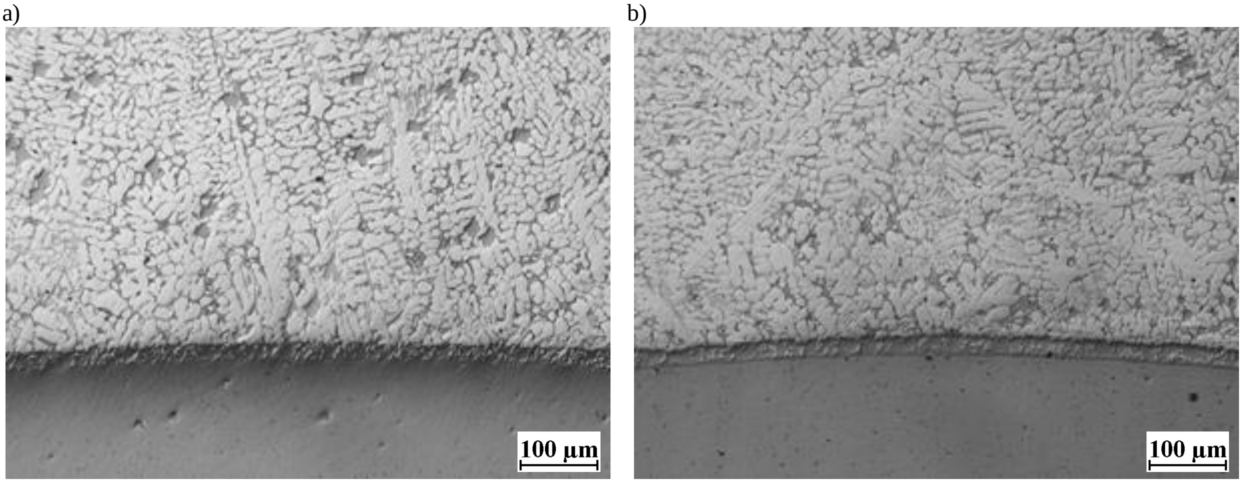


Fig. 9 (a-c). Microstructure of the connecting area of the bimetallic casting *X6CrNiTi18-10 – AlSi5Ni5Cu4MgCrMoVW* obtained at different pouring temperature values "t_z": a – 750°C, b – 800°C and c – 850°C

a)   b)



c)

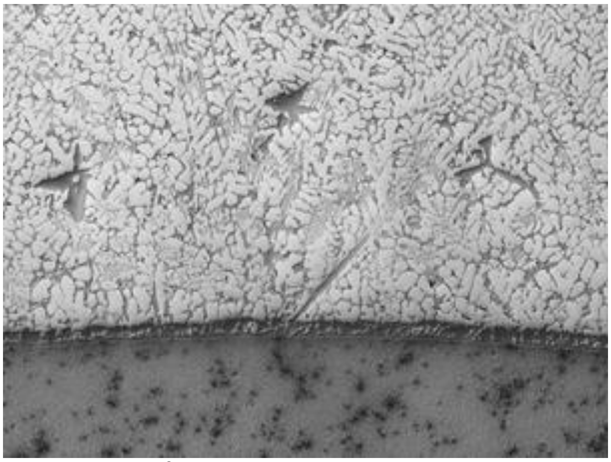
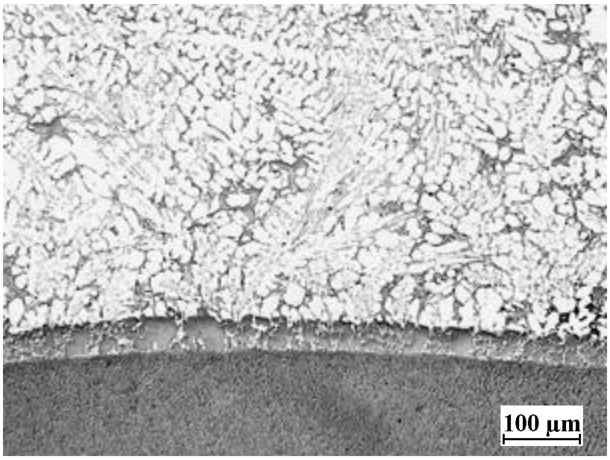


Fig. 10 (a-c). Microstructure of the connecting area of the bimetallic casting *X39Cr13 – AlSi5Ni5Cu4MgCrMoVW* obtained at different pouring temperature values "t_z": a – 750°C, b – 800°C and c – 850°C

a)



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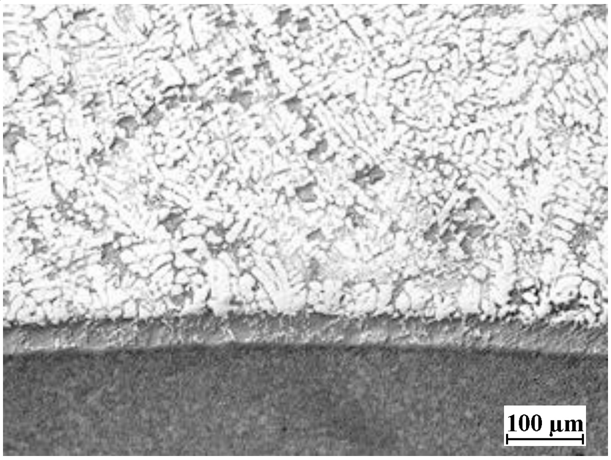

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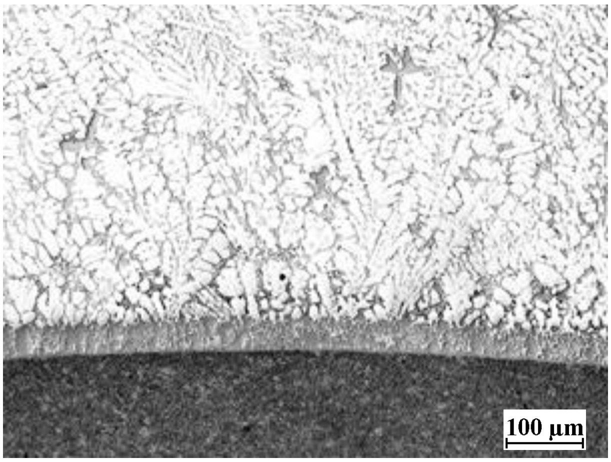

Fig. 11 (a-c). Microstructure of the connecting area of the bimetallic casting *HS6-5-2 – AlSi5Ni5Cu4MgCrMoVW* obtained at different pouring temperature values "t_z": a – 750°C, b – 800°C and c – 850°C

It follows from the presented data that irrespective of the set material and temperature value of the silumin for pouring into the casting mold, between the silumin of the bimetallic casting and the external layer of the coating there is no oxide layer which separates these two areas. Thus, smelting of the alphinizing coating with the complex silumin poured into the casting mold was obtained in all tested bimetallic castings. In all tested castings the continuity of the diffuse transition layer “g_{1p}” behaved the same. Different thickness of this layer in all alloy steel grades was obtained for the tested temperature values “t_z”. They are given in Table 3. It follows from the data presented in the table that the thickness of layer “g_{1p}” decreases in all tested alloy steel grades when the temperature “t_z” increases. When the temperature of the silumin poured into the casting mold is too high, more intensive smelting of the alphinizing coating takes place. As a result of the transition layer smelting, the component elements of the intermetallic phases which they consist of, penetrate into the liquid silumin. It causes crystallization of a larger quantity of free precipitates of intermetallic phases in the silumin part of the casting close to layer “g_{1p}” or appearance of large column crystals which grow immediately from these phases (Fig. 10c). When making bimetallic castings with steel sets which contain a lot of carbides (such as HS6-5-2) using high temperature value “t_z” causes their more intensive penetration into the silumin part of the casting. These carbides are partially dissolved by aluminum contained in the silumin, thus in the area of the connection they crystallize additional intermetallic phases consisting of Al and Si as well as the carbide components. These phases have a column structure.

Table 3.
The thickness of the transition layer of bimetallic castings “g_{1p}” made in the system *alloy steel – silumin AlSi5Ni5Cu4MgCrMoWV*

Steel	**Temperature of the silumin for pouring into the casting mold „t_z”**		
	750°C		**750°C**
	Thickness of the transition layer of bimetallic casting „g_{1p}”, µm		
X6CrNiTi18-10	7.9	**X6CrNiTi18-10**	7.9
X39Cr13	33.9	**X39Cr13**	33.9
HS6-5-2	52.9	**HS6-5-2**	52.9

The process of appearance of the column phases from the carbides in the silumin part of the bimetallic casting is shown in Fig. 12 for the casting made in the system *HS6-5-2 – ASi5Ni5Cu4MgCr-MoVW* using the temperature t_z = 800°C. The carbides of this type are typical for the alloys Fe–V–C [6]. The analyzed high-speed steel contains more wolfram (6.75%) than vanadium (1.76%), thus it can be assumed that these are carbides which mainly consist of wolfram and have a little part of vanadium. Heating the silumins to the temperature over 800°C causes intensive absorption of the surrounding hydrogen by the silumins which additionally increases with the growth in the silumin temperature [7]. As a result of this, the silumin casting made at such high temperature “t_z” is exposed to the danger of hydrogen gasification which appears in it.

It follows from the presented data that the correct production of all tested bimetallic castings is *HS6-5-2–AlSi5Ni5Cu4MgCrMoVW* regarding to smelting of the silumin poured into the casting mold with the coating and preserving of the diffusive layer continuity. Though taking into account the fact of appearance of the column crystals of the intermetallic phases growing from the transition layer and gasification of the silumin of the bimetallic casting at temperature values over t_z = 800 and 850°C, it is necessary to use lower temperature values t_z = 750°C.

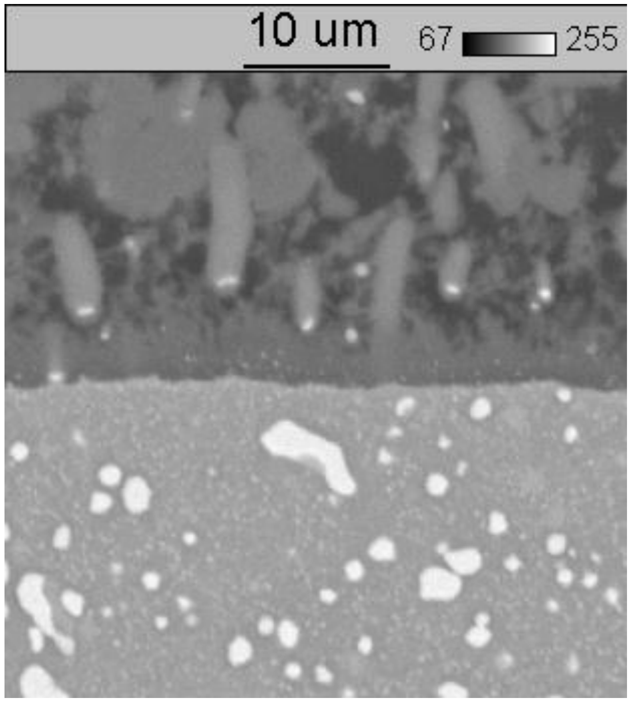

Fig. 12. The area of the connection in the casting *HS6-5-2 – ASi5Ni5Cu4Mg-CrMoVW* with column phases appeared from the dissolved carbides. Temperature t_z = 800°C

4. Conclusions

The following conclusions follow from the data presented in this work:

- the time „τ_p" from taking the set out of the alphinizing bath till pouring it with silumin into the casting mold for all tested materials of the set should not be more than 30s,
- the best (fine-grained) microstructure of the silumin part of the tested bimetallic castings was obtained at the low temperature values of the initial heating of the casting mold, that is $t_{2,0}$ = 100°C.
- the temperature of the silumin for pouring into the casing mold should be as low as possible (t_z = 750°C).

Acknowledgments

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